20th annual

NEW MEXICO
MINERAL SYMPOSIUM

November 13 & 14, 1999

Utah Colorado
Arizona New Mexico

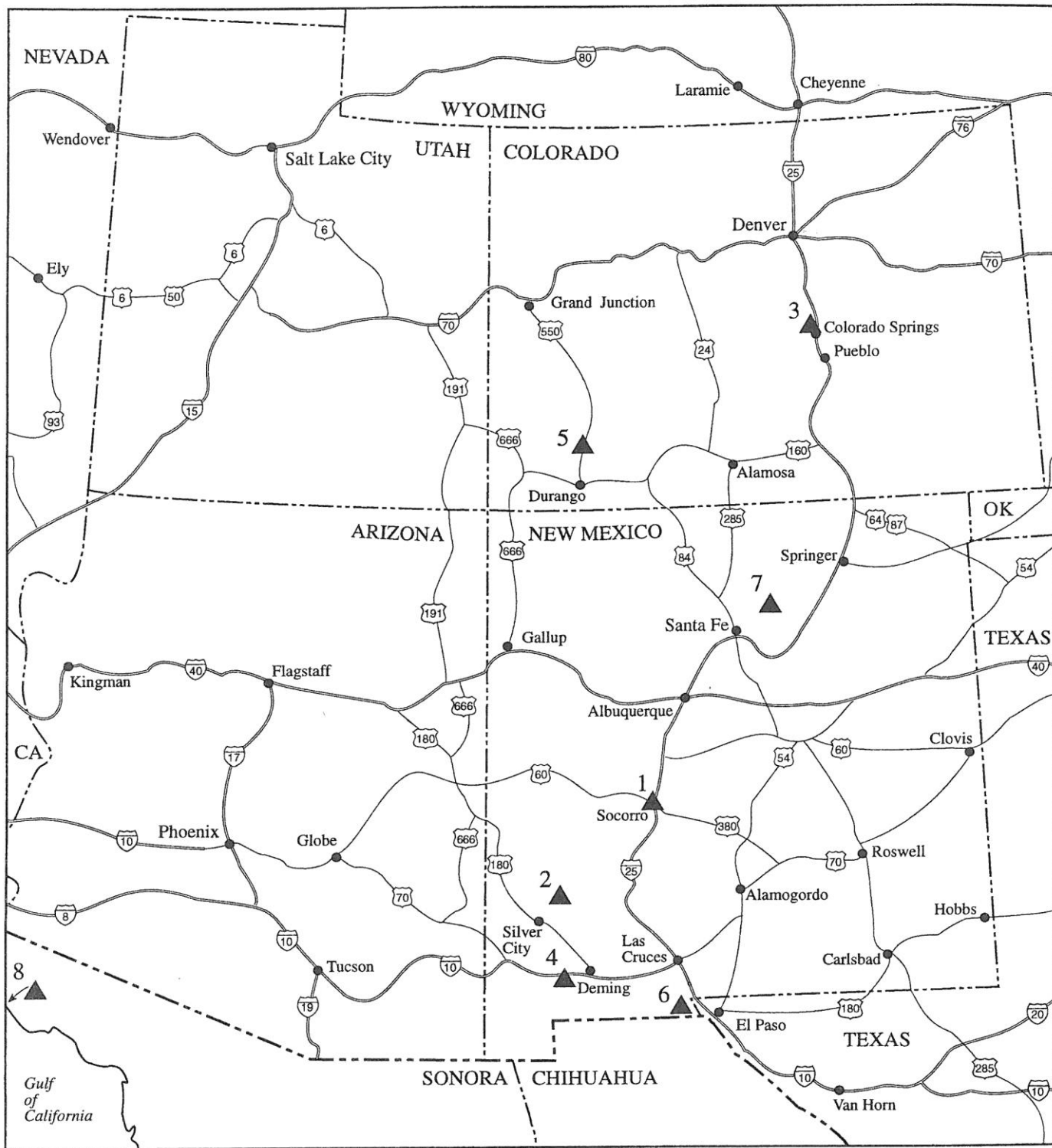## NMIMT Campus, Socorro, New Mexico

Welcome to

THE TWENTIETH ANNUAL

NEW MEXICO MINERAL SYMPOSIUM

NOVEMBER 13 AND 14, 1999

Macey Center Auditorium
New Mexico Institute of Mining and Technology
Socorro, New Mexico

Sponsored by
New Mexico Bureau of Mines and Mineral Resources
Albuquerque Gem and Mineral Club
Los Alamos Geological Society
New Mexico Geological Society
Chaparral Rockhounds

The purpose of the New Mexico Mineral Symposium is to bring together for an exchange of ideas both professionals and amateurs interested in mineralogy. The sponsors hope that the Twentieth New Mexico Mineral Symposium will give both groups a forum to present their cumulative knowledge of mineral occurrences in the state. In addition to the formal papers, informal discussions among mineralogists, geologists, and hobbyists should benefit all.

COVER—MINERALS OF THE FOUR-CORNERS STATES. Scepter quartz from Kingston, New Mexico; rhodochrosite from Silverton, Colorado; topaz from the Thomas Mountains, Utah; and barite from Superior, Arizona, represent the four-corners states in the cover design by Teresa Mueller.

NEVADA

WYOMING

Laramie Cheyenne

UTAH COLORADO

Wendover

Salt Lake City

Ely

Denver

Grand Junction

3 Colorado Springs
Pueblo

5

Alamosa

Durango

ARIZONA NEW MEXICO

OK

Springer

7

Santa Fe

TEXAS

Gallup

Kingman

Flagstaff

Albuquerque

Clovis

CA

Socorro 1

54 60

380

Phoenix

Globe

Roswell

2

Alamogordo

Hobbs

Silver City

4

Las Cruces

Carlsbad

Tucson

Deming

6

El Paso

180

TEXAS

8

SONORA CHIHUAHUA

Van Horn

Gulf of California

Geographic Index Map
20th New Mexico Mineral Symposium

SCHEDULE

Numbers in parentheses refer to geographic location on index map.

Friday, November 12

6:00 pm	Informal tailgating and social hour, individual rooms, Super 8 Motel

Saturday, November 13

8:30 am	Registration, Macey Center; continental breakfast
9:20	*Opening remarks,* main auditorium
9:30	*(1) Reminiscences on 20 years of the New Mexico Mineral Symposium* —Peter Modreski
10:00	*(2) Geology and mineralogy of the Fierro area of the Hanover–Fierro mining district, Grant County, New Mexico* —Robert North and Virgil Lueth
10:30	Coffee break
11:00	*(3) The Willet Raney Willis micromineral collection at the U.S. Air Force Academy, Colorado Springs* —Urban Turzi and Jack Thompson
11:30	*(4) Preliminary mineralogy of the Victorio district, New Mexico* —Nelia Dunbar and Virginia McLemore
12:00 pm	Lunch
1:00	Museum tours
2:00	*Mineral collecting in Iron Country* —Ray DeMark
2:30	*(5) Mineral occurrences in the Leadville Limestone, Ouray–San Juan Counties, Colorado* —Tom Rosemeyer
3:00	Coffee break
3:30	*(6) A view of the crust beneath southern New Mexico as shown from a collection of crustal xenoliths taken from the Kilbourne Hole maar* —Mark Ouimette and Brady Kolb
4:00	*Mineralogy: applications to nuclear waste disposal* —Rodney Ewing, featured speaker
5:30	Sarsaparilla and suds: cocktail hour, cash bar
6:30	Dinner followed by an auction to benefit the New Mexico Mineral Symposium

Sunday, November 14

8:15 am	Morning social: coffee and donuts
9:00	Welcome to the second day of the symposium and follow-up remarks
9:10	*(7) Pecos copper camp–Hamilton mine: past and present* —Dale and Diane Wheeler
9:40	*(8) A geological traverse of the Baja Peninsula, Mexico* —Anna Domitrovic
10:10	Coffee break
10:40	*The ugly ores of silver: part II– a photo gallery* —Andrew Regis
11:10	*Causes of color in minerals and gemstones—part II* —Paul Hlava
12:00 pm	Lunch
1:15-3:00	Silent auction, upper lobby, Macey Center, sponsored by the Albuquerque Gem and Mineral Club (FREE)

Reminiscences on 20 years of the New Mexico Mineral Symposium

Peter J. Modreski
U.S. Geological Survey
MS 915, Box 25046 Federal Center
Denver, CO 80225

(Location 1 on index map)

The New Mexico Mineral Symposium was organized in 1979 to provide an opportunity for amateurs and professionals interested in the mineralogy of New Mexico to meet and exchange information about minerals and their occurrence in the state. The first symposium was held in Northrop Hall of the University of New Mexico (UNM) on September 29-30, 1979. The co-chairmen were Ramon S. DeMark, Rodney C. Ewing of UNM, and Peter J. Modreski, and the symposium was identified as being cosponsored by the Albuquerque Gem and Mineral Club, UNM Geology Department, and Friends of Mineralogy. It was Ray and I who basically conceived the idea of a symposium and started organizing it. This first symposium consisted of 10 talks held on Saturday and a field trip Sunday to the Blanchard mine, Bingham, New Mexico. This was in the old days when a visit to the Blanchard mine with its well-known and well-crystallized fluorite, barite, and galena was a special event that required permission from the company, Hansonburg Mines, Incorporated, that was then working the property.

The second and all subsequent symposia were held on the New Mexico Institute of Mining and Technology (NMIMT) campus in Socorro, New Mexico, under the sponsorship of the New Mexico Bureau of Mines and Mineral Resources. Cosponsors over the years have included the Albuquerque Gem and Mineral Club, New Mexico Tech Mineralogical Society, Los Alamos Geological Society, New Mexico Geological Society, Chaparral Rockhounds, UNM Department of Geology, New Mexico Museum of Natural History, New Mexico Tech Earth & Environmental Science Department, and New Mexico Tech Cooney Mining Club.

After the second symposium in 1980, there was a gap of a year when no symposium was held. It seemed to have been the feeling at the time that perhaps there was only enough interest to support a biennial symposium. However, enthusiasm appeared high after the 1982 symposium, and it has been an annual event on the NMIMT campus ever since (held from 1980-84 usually in Weir Hall and from 1985 onward in the Macey Center auditorium). New Mexico Bureau of Mines and Mineral Resources staff organized and chaired the symposia; Robert M. North was the chair from 1980-87, Marc L. Wilson from 1989-91, and Virgil W. Lueth from 1994 to the present, with Robert W. Eveleth regularly assisting and doing the job during the intervening years.

Beginning in 1983, keynote speakers were invited to give a special presentation (or two), starting with the Bureau's own Bob Eveleth. Bob's talk and slide show, presented in a somewhat impromptu setting in the back of the El Matador Lounge at the El Camino restaurant, was a particularly enjoyable and memorable one for its treatment of the tall tales and shifty characters in New Mexico's mining history. His talk may also qualify for the longest title of a presentation at the symposium (see table of symposium titles).

A Saturday evening banquet became a regular feature of the symposium starting in 1984; these were held in the Macey Center except for 1989-92 when the banquet was in the quaint and historic (but acoustically challenged) Garcia Opera House. Collectors who wished to sell or swap specimens began setting up mineral displays in their rooms at the El Camino Motel, starting on Friday evening, and this has become an "officially" publicized feature since the 6th (1985) symposium. In 1993 the "tailgating" was moved to the Super 8 Motel, which then became the principal conference motel.

The first three symposia included field trips held on Sunday. As previously noted, the first year's trip was to the Blanchard mine, the second trip was to the Magdalena district (Graphic—Waldo and Lynchburg mine dumps), and the third was to the Orogrande district, Otero County. In 1984 and thereafter no formal field trip was held, and the symposium talks were expanded to 1.5 days, with a silent auction held on Sunday afternoon. In lieu of a field trip, field guides for self-guided trips to various mineral localities in the state were prepared by the Bureau and made available at the symposium.

Looking back at past topics presented at the symposium, the first symposium included papers on several areas then relatively little known but now considered "classic" New Mexico mineral localities: the Red Cloud fluorite-copper-rare earth deposit in the Gallinas Mountains, and the red beryl and pseudobrookite occurrence near Paramount Canyon in the Black Range, as well as papers on the Harding pegmatite, the Blanchard mine (Hansonburg district), and others. The 3rd (1982) symposium saw the first paper, by Ray DeMark, on the unusual minerals of the Point of Rocks phonolite sill (a locality that provided subject matter for a number of subsequent talks). The first presentation about minerals from the schists in the Picuris Range near Pilar was made in 1986, also by DeMark who described cyprine (blue vesuvianite), piemontite, thulite (pink zoisite), and associated minerals. Talks at the first three symposia were limited to localities in New Mexico, but beginning in 1983 with a talk by

Richard Graeme on Bisbee, Arizona, talks on neighboring states, Mexico, and occasionally beyond have been included. Beginning in 1982, abstracts of those papers dealing with New Mexico were reprinted in *New Mexico Geology* in addition to being printed in the abstract booklet distributed at the symposium.

Invited keynote speakers and their presentations from the first 20 symposia are listed below. A table giving additional details about each symposium and the featured speakers was included in the article by Eveleth and Lueth (1997) about the history of the Mineral Museum.

1979   (1)

1980   (2)

1981   no symposium

1982   (3)

1983 (4) Robert W. Eveleth, Of Bridal Chambers, jewelry shops, and crystal caverns – a glimpse at *New Mexico's mining camps, characters, and their mineral treasures*

1984 (5) Laurence H. Lattman, President, New Mexico Institute of Mining & Technology, *High-tech materials for modern society*

1985   (6) Peter Bancroft, Gem and crystal treasures

1986 (7) Vandall T. King, Pegmatite petrology through phosphate mineralogy

1987 (8) Robert W. Jones, Copper throughout history

1988   (9) Peter Bancroft, Gem and mineral treasures II

1989(10) Philip C. Goodell and Kathryn Evans Goodell—Adventures in the Sierra Madre, Batopilas, *Chihuahua*

1990 (11) Peter K.M. *Megaw—Mineralogy of the rhodochrosite-bearing silicate ore-bodies of the Potosi mine, Santa Eulalia mining district, Chihuahua, Mexico*

1991   (12) Gilbert Gauthier Mineral classics of Shaba, Zaire

1992 (13) Stanley J. Dyl, *II—Mining history and specimen mineralogy of the Lake Superior copper district*

1993 (14) Bernard *Kozykowski—Franklin—its mines and minerals; The Sterling mine—a precious hillside preserve*

1994 (15) Fred Ward—The *precious gems: where they occur, how they are mined* and *Jade*

1995 (16) Dr. Miguel Romero Sanchez—The *Romero Mineral Museum*

1996 (17) Robert W. *Jones—Gemstones of Russia*

1997 (18) Carl A. Francis—A *fourth world occurrence of foitite at Copper Mountain, Taos County, New Mexico* and *New Mexico minerals at Harvard*

1998(19) Terry Huizing—Collectible minerals of the midwestern United States and Colorful calcites

1999 (20) Rodney Ewing—Mineralogy, applications to nuclear waste

Reference

Eveleth, R.W., and Lueth, V.W., 1997, A rocky history—the first 100 years of the Mineral Museum in Socorro, New Mexico, USA: New Mexico Geology, v. 19, no. 3, pp. 65-75.

Geology and mineralogy of the Fierro area of the Hanover—Fierro mining district, Grant County, New Mexico

Robert M. North
Phelps Dodge Chino Mines Company
Hurley, NM, 88043

Virgil W. Lueth, Ph.D.
New Mexico Bureau of Mines
Socorro, NM 87801

(Location 2 on index map)

The Hanover—Fierro (H-F) mining district extends from the community of Hanover north to mines in Shingle Canyon, northeast of the Continental mine. The host-rock stratigraphy consists of Paleozoic limestones, dolomites, and shales, overlain by Cretaceous siliceous sedimentary rocks, capped by middle Tertiary volcanic rock. The most important ore hosts are the Pennsylvanian Oswaldo Formation and the Mississippian Lake Valley Formation. Limestones in the Ordovician El Paso Formation also host chalcopyrite skarn. Late Cretaceous quartz-diorite sills and Tertiary dikes intrude the stratigraphic section, with little or no associated mineralization.

The major structural features of the district are the contacts of the stock and the Barringer fault zone, located near the northern end of the H—F stock near the community of Fierro. The Barringer fault, which pre-dates the stock and mineralization, is a major feature that forms the northwestern edge of the Santa Rita horst. The fault strikes north 75°-80° east, dipping steeply northwest on the west side of the stock, changing to a strike of about north 30°-40° east, dip of 60°-75° northwest to the northeast of the stock. Displacement to the west is about 1,600 ft, and 1,400 ft on the northeast. In the area of Hanover Mountain, the fault juxtaposes the Cretaceous Colorado Formation with the Paleozoic Lake Valley and Percha Formations, indicating about 1,400 ft of displacement. The fault zone acted as an important conduit for mineralizing solutions in the district. The important stock contacts run north south on the east and west sides of the stock where the Paleozoic rocks have been domed by the force of the intrusion. In the Fierro area, the lower Paleozoic rocks on the footwall of the Barringer fault and on the east side of the stock, dip steeply (+80°) to the east. Upper Paleozoic rocks on the hanging wall of the Barringer and on the west side of the stock, dip more gently (20°-25°).

Copper mineralization in the Continental mines (open pit and underground) near Fierro is in skarns associated with the 57 Ma H—F granodiorite stock. A large quartz-sericite-pyrite (QSP) hydrothermal alteration event involving large amounts of meteoric water did not occur at Hanover—Fierro as was the case at Santa Rita and Tyrone. As such, the district has little supergene enrichment. Most primary copper at H-F is hosted in skarns within the Paleozoic limestones and, to a lesser extent, dolomites around the north end of the stock. The skarns did not undergo a strong retrograde alteration event. The differences between Santa Rita and H—F suggest a deeper level of emplacement for the Hanover—Fierro stock. Weak to moderate QSP alteration is present in the Colorado Formation at Hanover Mountain, which has resulted in the formation of a relatively small chalcocite enrichment blanket on the hanging wall of the Barringer fault northeast of the Continental pit. The fault itself is also host of oxidized copper mineralization, most notably azurite roses from the Hanover #2 mine and a limited amount of turquoise.

Iron skarns are common in dolomitic units of the lower Paleozoic section. These units are in contact with the H—F stock in the middle stretches of the intrusive between the zinc deposits to the south and copper to the north. The Fusselman and Montoya Formations are the most common hosts. The iron occurs as magnetite, with much less specular hematite. Copper as chalcopyrite has been produced from some of the iron mines from the El Paso Formation underlying the Fusselman and Montoya Formations.

Minerals reported from the Fierro Area of the Hanover–Fierro mining district, Grant County, New Mexico

Native elements

*Copper	Cu
Gold	Au
Silver	Ag

Sulfides and Sulfosalts

Bornite	Cu_5FeS_4
*Chalcocite	Cu_2S
*Chalcopyrite	$CuFeS_2$
Covellite	CuS
Cubanite	$CuFe_2S_3$
Digenite	Cu_9S_5
Galena	PbS
Molybdenite	MoS_2
Pyrrhotite	$Fe_{1-x}S$
*Pyrite	FeS_2
Sphalerite	ZnS
Tetrahedrite/Tennantite	$(Cu,Fe)_{12}(Sb,As)_4S_{13}$
Valleriite	$4(Fe,Cu)S_{0.3} (Mg,Al)(OH)_2$

Oxides

*Cuprite	Cu_2O
*Goethite	$\alpha\text{-}Fe^{+3}O(OH)$
Hematite	Fe_2O_3
Ilmenite	$FeTiO_3$
*Magnetite	Fe_3O_4
Pyrolusite	MnO_2
Rutile	TiO_2

Carbonates

Ankerite	$Ca(Fe,Mg,Mn)(CO_3)_2$
Aragonite	$CaCO_3$
*Azurite	$Cu_3(CO_3)_2(OH)_2$
*Calcite	$CaCO_3$
Cerussite	$PbCO_3$
Hydromagnesite	$Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$
Magnesite	$MgCO_3$
Malachite	$Cu_2CO_3(OH)_2$
Rhodochrosite	$MnCO_3$
Siderite	$FeCO_3$

Sulfates

Brochantite	$Cu_4(SO_4)(OH)_6$
*Chalcanthite	$CuSO_4 \cdot 5H_2O$
Gypsum	$CaSO_4 \cdot 2H_2O$
Jarosite	$KFe^{+3}_3(SO_4)_2(OH)_6$

Phosphates/Vanadates

Apatite	$Ca_5(PO_4)_3(F,OH,Cl)$
*Turquoise	$CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$

Silicates

Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
Allophane	
Antigorite	$(Mg,Fe)_3Si_2O_5(OH)_4$
Augite	$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$
Biotite	$K(Mg,Fe)_3Si_3AlO_{10}(OH,F)$
Chabazite	$(Na,K,Ca)_4[Al_4Si_8O_{24}] \cdot 12H_2O$
Chamosite	$(Fe,Mg)_5Al(Si_3Al)O_{10}(OH,O)$
Chlorite	$(Fe,Mg,Al)_6(Si,Al)_4O_{10}(OH,O)_8$
Chrysocolla	$(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$
Cordierite	$Mg_2Al_4Si_5O_{18}$
Diopside	$Ca(Mg,Fe)Si_2O_6$
Epidote	$Ca_2(Al,Fe^{+3})_3(SiO_4)_3(OH)$
*Garnet (Grandite series)	$(Ca,Fe^{+2})_3 (Al,Fe^{+3})_2(SiO_4)_3$
Glauconite	$KR_2 \square AlSiO_{10}(OH)_2$
Ilvaite	$Ca Fe^{+2}_2 Fe^{+3}(SiO_4)_2(OH)$
Halloysite	$Al_2Si_2O_5(OH)_4$
Hemimorphite	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$
Hornblende	$Ca_2(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$
Illite	$(K,H_3O)Al_3(Si_3Al)O_{10}(H_2O,OH)_2$
Kaolinite	$Al_2Si_2O_5(OH)_4$
Laumontite	$Ca_4[Al_8Si_{16}O_{48}] \cdot 18H_2O$
Mesolite	$Na_{16}Ca_{16}[Al_{48}Si_{72}O_{240}] \cdot 64H_2O$
Montmorillonite	$(Na,Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$
Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)_2$
Orthoclase	$KAlSi_3O_8$
Plagioclase	$(Na,Ca)(Al,Si)_3O_8$
Quartz	SiO_2
Scapolite Group	$(Na,Ca)_4(Al,Si)_{12}O_{24}(Cl,CO_3,SO_4)_{12}$
*Scolecite	$Ca[Al_2Si_3O_{10}] \cdot 3H_2O$
Serpentine	$(Mg,Fe)_3Si_2O_5(OH)_4$
*Stilbite	$(Ca,Na,K)_9[Al_9Si_{27}O_{72}] \cdot 28H_2O$
Talc	$Mg_3Si_4O_{10}(OH)_2$
Titanite	$CaTiSiO_5$
Topaz	$Al_2 SiO_4(F,OH)_2$
Tourmaline	$NaFe_3Al_6(BO_3)_3Si_6O_{18}(O,OH,F)_4$
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
Vermiculite	$(Mg,Fe,Al)_3(Si,Al)_4O_{10}(OH)_2 \cdot 4H_2O$
Vesuvianite	$Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$
Wollastonite	$Ca(Mg,Fe)Si_2O_6$
Zircon	$ZrSiO_4$
Zoisite	$Ca_2Al_3(SiO_4)_3(OH)$

The Willet Raney Willis micromineral collection at the
U.S. Air Force Academy, Colorado Springs

Urban J. Turzi*
1486 Friendship Lane East
Colorado Springs, CO 80904

Jack Thompson**, GeologyAssociate
Denver Museum of Natural History
1830 Mesita Court
Colorado Springs, CO 80906

(Location 3 on index map)

The United States Air Force Academy in Colorado Springs, Colorado, houses a small treasure that warrants the distinction of being in the "Who's Who" of micromineral collections. Located in a classroom in the Department of Economics and Geography in Fairchild Hall are the approximate 3,000 micromounts of the late Willet Raney Willis. The collection was donated to the Academy by his family after his death in 1968; also included are Willis' brass microscope and various black and white stereophotographs of microminerals taken by Willis. Closer inspection of this collection reveals an assemblage of minerals from some of the more historical figures in the mineralogical annals of the United States.

Willet Raney Willis was born in 1881 in La Veta, Colorado, and graduated from Colorado College in Colorado Springs. A chemistry teacher by trade, he taught in public schools. His interests included photography, hummingbirds (in fact, one of his micromounts includes a hummingbird feather), concert music, and crystallized minerals. His interest in minerals was heightened when one of his students introduced him to another Colorado Springs resident, Lazard Cahn, who greatly broadened his knowledge of microscopic minerals. Willis met a couple of times a week with several other locals to study microminerals under Cahn's tutelage. This study group became the nucleus for the establishment of the Colorado Springs Mineralogical Society (CSMS) in 1936 with Lazard Cahn serving as its Honorary President and Willis as the society's first president. Willis was known for his mild manner and gentlemanly qualities.

The Willis mineral collection resides in an old wooden antique case that is only a few feet in height, depth, and width. All of his mineral specimens are mounted on cork pedestals in cardboard boxes with detachable lids (i.e., Rakestraw mounts). The information on the labels of each box is admirably documented with mineral name, location, date collected or acquired, name of donor where applicable, and in some cases, the chemical formula for the mineral (evidence of his chemistry background, no doubt) all noted on the lid of the box. The time frame when the majority of the collection was put together ranges from the 1930s through the 1950s The exact number of species of minerals has not been counted, but it is estimated to be between 200 and 250.

Willis' profession as a chemistry teacher is evident in his collection. There are a number of artificial (i.e., manmade) mounts provided by his high school chemistry students. These could have been part of their course of study or done as a hobby-related activity by these teenagers in the 1930s and 1940s.

Lazard Cahn's influence on Willis is evident throughout the collection. Quintin Wight (1996) says of Cahn: "In North America during this period, it is safe to say that the senior micromounter was Lazard Cahn."

Some 120 different individuals and institutions are represented in this collection (Wight, 1993). The institutions include the Colorado School of Mines, the American Museum of Natural History, the Philadelphia Academy of Natural Sciences, and the Colorado Springs Pioneer Museum. Willis was quite fastidious in documenting the ownership lineage of most of his mineral specimens. One example is a micromount with the following written on the label, along with the mineral's name, locality, and date collected: "Fiss-Palache-Keeley-Mrs. Thomas-Willis."

Some of the more notable mounts include specimens from Dr. Charles Palache, George W. Fiss, George C. Rakestraw, Clarence S. Bement, Louis Perloff, Neal Yedlin, Edwin Over, Richard Pearl, Arthur Montgomery, Arthur Roe, Frederick Pough, Winfield Scott Stratton, George L. English, Alice H. Thomas, L. C. Wills, Peter Zodac, Frank J. Keeley, and Paul Seel.

A small portion of this collection is continually on display in the hallway outside of the geography classrooms at the Air Force Academy.

References

Oldach, D., 1995, Here lies Colorado Springs: City of Colorado Springs

Wight, Q, 1993, Complete book on micromounting: The Mineralogical Record, Tucson.

Wight, Q., 1996, Some significant micromineral collections—where are they now?: Rocks & Minerals, v. 71, pp. 402-407.

*authored article for Rocks & Minerals magazine, May/June1999
** mineral photography

Preliminary mineralogy of the Victorio district, New Mexico

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New Mexico Bureau of Mines and Mineral Resources
New Mexico Institute of Mining and Technology,
Socorro, NM 87801

(Location 4 on index map)

The Victorio mining district, located in the Victorio Mountains, Luna County, hosts three types of deposits. These are (1) carbonate-hosted lead-zinc replacement, (2) tungsten-beryllium-molybdenum skarn-vein-tactite, and (3) porphyry-type molybdenum deposits.

Most of the production from the district came from the carbonate-hosted Pb-Zn replacement deposits that occur as oxidized replacements and veins within Ordovician and Silurian dolomites and limestones. The more productive deposits are along faults or fractures that strike N30°-65°E and dip steeply east. Brecciation, dissolution, and recrystallization of the dolomites are common in the vicinity of the mineral deposits. Ore minerals include galena, smithsonite, cerussite, and anglesite with rare sphalerite, galena, and chalcopyrite in a gangue of quartz, calcite, and iron oxides. Lead typically exceeds zinc and copper in abundance. Ore at the Rambler mine averaged 12.5% Pb and 3.9% Zn. Gold assays range as high as 5,500 ppb. Carminite, kolfanite, adamite, vanadinite, and wulfenite have also been reported (Beyer, 1997).

Drill cores collected in the vicinity of the Victorio Mountains yield mineralogically diverse samples, and examples of what appear to be skarn-associated vein and replacement-texture deposits, as well as igneous granite, were studied using the electron microprobe. Using this instrument, textural relationships as well as quantitative and qualitative chemical compositions of metal-bearing and gangue minerals were investigated. A diverse mineral assemblage was found within the gangue minerals of the samples that were interpreted to be replacement-texture and vein skarn deposits. Garnet, a wide compositional range of pyroxenes, actinolite, serpentine, phlogopite, calcite, quartz, talc, and fluorite were recognized. The assemblages present in the samples that appear to be replacement-texture deposits are indistinguishable from those that are veins and are likely to represent the same mineralization event. The mineral assemblage, particularly the presence of serpentine, magnesian pyroxene, phlogopite, and talc and the absence of wollastonite and apatite, suggests that the Victorio Mountains skarn system should be classified as magnesian rather than calcic (e.g. Kwak, 1994). The presence of fluorite further suggests that the skarn-related fluids were F-rich. Mineralogy and textural relationships observed in both replacement-texture and vein deposits suggest that remnants of a primary, or prograde, skarn assemblage are present, as well as a number of secondary, or retrograde phases. In one sample, large (-1 cm) complexly zoned garnets, interpreted to be part of a prograde skarn assemblage, are present in an open-space filling vein. In a nearby part of the same sample, smaller garnets co-exist with phlogopite, serpentine, and talc and are interpreted to be part of a retrograde facies. Other samples record similar ranges of mineral phases. In one case, delicate, fan-shaped masses of phlogopite appear to have crystallized in open-space cavities, which possibly formed during prograde skarn evolution. Serpentine, a mineral that would form at a later stage of prograde evolution than phlogopite, is found around and intergrown with the phlogopite. Hence, the replacement-texture and vein samples from Victorio Mountains appear to record an extended history of skarn formation, spanning a range of fluid concentrations and formation temperatures.

A range of metal-bearing minerals is observed in the skam-related samples. These include euhedrel rods or masses of molybdenite, masses of molybdenum-bearing scheelite, and an iron sulphide. The metal-bearing minerals are more abundant in the vein samples than in the replacement-texture samples. In some cases, bands of concentrated metal-bearing phases are present along vein margins, suggesting an interval of favorable conditions for ore formation during the growth of the veins.

One sample of granite from the Victorio Mountains area was analyzed and appears to contain a normal mineral assemblage of quartz, potassic feldspar, biotite, albite, and magnetite. However, in addition to these phases, the granite contains abundant pinkish, manganese-rich garnets that include a high abundance of heavy-mineral inclusions and fluorite. These inclusions include hafnium-rich zircon and thorium-, uranium-, and yttrium-rich allanite. These phases appear to have crystallized from the granitic magma and may suggest that the Victorio Mountains granite may be anomalously enriched in heavy elements, as well as fluorine. Molybdenite and scheelite have also been observed in the Victorio Mountains granite.

The carbonate-hosted Pb-Zn replacement deposits in the Victorio district are epithermal deposits as evidenced by ore textures, ore controls, and correlations with similar carbonate-hosted replacement deposits in southwestern New Mexico that are also believed to be epithermal. The skarn-vein-tactite and porphyry-type Mo deposits are magmatic-hydrothermal deposits that appear to be related to the Victorio Mountains granite as evidenced by ore textures and similar mineralogy, metal associations, and alteration assemblages. However, the relationship between the carbonate-hosted replacement and skarn—porphyry-Mo deposits remains unknown. All three deposit types may be genetically related, or more than one mineralization event occurred forming the deposits at different times.

Selected minerals found in the Victorio mining district, Luna County (from Holser, 1953; Griswold, 1961; DeMark, 1992; Northrop and LaBruzza, 1996; Beyer, 1997; Gulf Minerals company reports; this study). Minerals in bold are newly reported in this study. Type of deposit in parenthesis: 1-carbonate-hosted Pb-Zn replacement deposits, 2-Be-Mo-W skarn-vein-tactite deposits, and 3-porphyry Mo deposits.

MINERAL	CHEMICAL FORMULA	MINERAL	CHEMICAL FORMULA
Pyrite (1, 2, 3)	FeS_2	Psilomelane (1, 2)	Mn oxide
Pyrrhotite (1, 2, 3)	Fe_xS	Molybdenite (2, 3)	MoS_2
Marcasite (1, 2)	FeS_2	Powellite (2)	$CaMoO_4$
Sphalerite (1, 2)	$(Zn, Fe)S$	Scheelite (2)	$CaWO_4$
Galena (1, 2)	PbS	Magnetite (2, 3)	Fe_3O_4
Calcite (I, 2, 3)	$CaCO_3$	Beryl (2, 3)	$Be_3Al_2Si_6O_{18}$
Quartz (1, 2, 3)	SiO_2	Bismutite (2)	$Bi_2(CO_3)O_2$
Chalcopyrite (1, 2)	$CuFeS_2$	Bismuthinite (2, 3)	Bi_2S_3
Wolframite (1, 2)	$(Fe, Mn)WO_4$	Galenobismutite (2, 3)	$PbBi_2S_4$
Bornite (1)	Cu_5FeS_4	Helvite (2)	$Mn_4Be_3(SiO_4)_3S$
Wurtzite (1)	$(Zn,Fe)S$	Danalite (2)	$Fe_4Be_3(SiO_4)_3S$
Cerussite (1)	$PbCO_3$	Hübnerite (2)	$MnWO_4$
Anglesite (1)	$PbSO_4$	Beyerite (2)	$(Ca, Pb)Bi_2(CO_3)_2O_2$
Gold (1)	Au	Chondrodite (2)	$(Mg, Fe)_5(SiO_4)_2(F, OH)_2$
Argentite (1)	Ag_2S	Humite (2)	$(Mg, Fe)_7(SiO_4)_3(F, OH)_2$
Chlorargyrite (1)	$AgCl$	Clinohumite	$(Mg, Fe)_9(SiO_4)_4(F,OH)_2$
Carminite (1)	$PbFe2(AsO_4)_2(OH)_2$	Scapolite (2)	$(Na,Ca)4Al_{3-6}Si_{6-9}O24$ (Cl,CO_3,SO_4)
Beudantite (1)	$PbFe_3(As,O_4)(SO_4)(OH)_6$	Diopside (2)	$CaMgSi_2O_6$
Bromargyrite (1)	$AgBr$	Fluorite (2, 3)	CaF_2
Kolfanite (1)	$Ca_2Fe_3O_2(AsO_4)_3*2H_2O$	Serpentine (2)	$(Mg, Fe, Ni)_3Si_2O_5(OH)_4$
Adamite (1)	$Zn_2(AsO_4)(OH)$	Tremolite (2)	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
Vanadinite (1, 2)	$Pb_5(VO_4)_3Cl$	Augite (2)	$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$
Wulfenite (1, 2)	$PbMoO_4$	Talc (2)	$Mg_3Si_4O_{10}(OH)_2$
Mimetite (1)	$Pb_5(AsO_4)_3Cl$	Phlogopite (2)	$KMg_3Si_3Al0_{10}(F, OH)_2$
Hemimorphite (1)	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$	Stolzite (2)	$PbWO_4$
Descloizite (1)	$PbZn(VO_4)(OH)$	Rhodochrosite (3)	$MnCO_3$
Willemite (1)	Zn_2SiO_4	Zircon (3)	$ZrSiO_4$

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Mineral collecting in Iron Country

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Mineral collecting in Michigan's Iron Country can be interesting and rewarding for the persistent collector. Iron Country for the purposes of this presentation will consist of the four central counties of Michigan's Upper Peninsula (Marquette, Baraga, Dickinson, and Iron). Iron mining in Michigan's Upper Peninsula began in 1845 at the Jackson mine near the present town of Negaunee. From 1845 to the present, 247 iron mines were to operate on what was to become the Marquette Iron Range. The Menominee Iron Range in Dickinson and Iron Counties also had many iron mines, the last of which operated up until 1981.

Many of these mines left open pits and poor rock piles and dumps that beckon to the collector of minerals. Hematite, goethite, pyrite, calcite, barite, and manganese minerals are commonly found in these areas. Micro crystals of apatite, rhodochrosite, dolomite, sammetblende goethite, filiform pyrite, chalcopyrite, and gypsum can also be collected. Chloritized garnets from the Michigamee mine are distinctive and widely recognized.

Marquette County had the only operating gold mines in the region. The Michigan gold mine, north of the town of Ishpeming, produced the best specimen gold around the turn of the century, but the old dumps still produce free gold. The Ropes gold mine operated intermittently between 1881 and 1990 and produced dumps that can be accessed with permission. Specimens of antigorite, chrysotile, and green talc with dolomite are readily obtainable along with micro crystals of pyrrhotite, goethite, and even galena. Massive tetrahedrite and occasionally free gold can also be collected. Quartz veins and pegmatites in natural outcrops and mine prospects in the area have yielded some diverse minerals. Britholite-(Y) and xenotime-(Y) from the Black River pegmatite and chalcocite, azurite, and wroewolfeite from the Captain Daniels' "mine" are examples.

World class specimens of pyrolusite and manganite have come from the Taylor mine in Baraga County, and the location is still accessible. Recently, micro crystals of rhodochrosite and barite were found in the area. Marble quarries in Dickinson County have yielded excellent tremolite specimens and micro crystals of hematite, goethite, and marcasite. The now-closed (1981) Groveland mine near the town of Fekh has produced excellent calcite crystals along with pyrite, marcasite, and ferroan dolomite. Micro crystals of chalcopyrite are common.

Collecting on the mine dumps of Iron County will produce minerals similar to those found in Marquette County, but historically, the mines of Iron County have turned up some exceedingly rare minerals. The Chicagon mine near Iron River was until recently the only known location for seamanite, a hydrated manganese phospho-borate. The rare mineral shigaite, a hydrated manganese aluminum sulfate, has been found from two mines near Iron River. Attractive micro crystals of rhodochrosite have been collected recently from the dumps of the Chicagon mine.

Mineral collecting in Iron Country can be challenging due to vegetation, insects, and the climate, but new and exciting mineral discoveries are being made, even today.

Mineral occurrences in the Leadville Limestone, Ouray—San Juan Counties, Colorado

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(Location 5 on index map)

In the San Juan Mountains of southwestern Colorado, the Leadville Limestone of Mississippian age is the host rock for a number of small but outstanding mineral occurrences. Most of these non-commercial deposits are quartz veins and solution cavities that contain superb quartz crystals ranging up to 19 inches long and encrustation pseudomorphs of quartz after barite and calcite.

The Amphitheater, just east of Ouray, is an area that has produced large, world-class milky-quartz crystals from a large solution cavity and enormous milky-quartz crystals from a large vug in a crystalline-quartz vein.

Within the city limits of Ouray, a solution cavity was discovered that contained a number of fine encrustation pseudomorphs of quartz after large, bladed barite crystals. Just a short distance from this locality, another pocket produced large, brown calcite crystals implanted on small quartz crystals.

The Mineral Farm mine, which is one of the few economic operations in the Leadville Limestone, has produced fine quartz crystal groups along with crystallized tetrahedrite, sphalerite, and pyrite.

In the Ironton Park area, which is located south of Ouray, an igneous intrusion on the edge of the Leadville Limestone has produced a small skarn deposit. Superb micro crystals of prehnite, epidote, grossular, and magnetite have been collected from the contact metamorphic zone. Another contact metamorphic deposit just south of Silverton has produced an exotic array of minerals.

A view of the crust beneath southern New Mexico as shown from a collection of crustal xenoliths taken from the Kilbourne Hole maar

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(Location 6 on index map)

The Kilbourne Hole maar is a young volcanic feature found 42 km southwest of Las Cruces, New Mexico, or 53 km west of El Paso, Texas. It is one of five Pleistocene maar volcanoes found near the Potrillo volcanic field. It is a well-known collecting locality for mantle and crustal xenocrystic and xenolithic material. Investigations and reports on the rocks found at Kilbourne Hole have provided detailed information about mantle and deep crustal processes that have operated under southern New Mexico.

Collecting xenoliths at Kilbourne Hole has been a popular activity for many years. Peridot is abundant, usually small in size, and easily found in a variety of mantle xenoliths. Kilbourne Hole also provides geologists with the opportunity to examine a diverse suite of crustal rocks. This suite includes representatives of lower, middle, and upper crustal lithologies plus a variety of volcanic rocks.

A Hardin—Simmons University geology field project, conducted in 1996, surveyed the distribution of crustal xenoliths. The purpose of the project was to determine if any distribution bias could be detected statistically. Several teams established sites to collect, describe, and count the xenoliths. Although no statistical difference in distribution was noted, a comprehensive description of the types of crustal rocks was obtained. An extended list of crustal xenoliths would include: alkalic basalt, granite, felsic porphyry, fossiliferous limestone, sandstone, arkose, various conglomerates and breccias, granodioritic gneiss, mafic granuloblastite, sillimanite-quartz granuloblastite, granulite, and pelitic granulite. Many of the crustal rocks were sectioned and photographed. Photomicrographs will show the variety of textures, minerals, and lithologies found at the Kilbourne Hole xenolith collecting locality.

Mineralogy: applications to nuclear waste disposal

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Mineralogy has had only a limited impact on present nuclear waste disposal strategies. This is due to the emphasis in performance and safety assessments on "geologic isolation" or the near-field engineered barriers (e.g., canister and backfill), rather than any significant reliance on "immobilization" or "containment" by durable materials, specifically designed for particular waste streams and defined geologic environments. However, highly durable ceramics can find unique applications in the immobilization and disposal of long-lived actinides, particularly the [239]Pu that results from the dismantling of nuclear materials. Radionuclides that are geochemically mobile, toxic, and fissile require special materials of high chemical and mechanical durability.

I will review the areas in which mineralogy can contribute to the long-term isolation of actinide elements. The presentation will specifically discuss the considerations that are required for the design of materials for the immobilization of different waste streams. Critical to the design of the waste form are: (1) waste stream composition, (2) processing technology, (3) long-term chemical and mechanical durability, (4) stability of alteration products, (5) radiation-solid interactions. Principal minerals to be considered include: silicates (zircon and titanite); phosphates (monazite and apatite); oxides (zirconolite, pyrochlore, and perovskite); and the UO_2 in spent nuclear fuel. Minerals can be used to evaluate long-term durability.

The immobilization of excess weapons plutonium in zircon and monazite will be discussed as a specific example of a solution for the disposal of excess weapons plutonium. A powerful aspect of this approach is the use of minerals to "confirm" projections of long-term behavior in a variety of geochemical environments.

**Pecos copper camp—Hamilton mine:
past and present**

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(Location 7 on index map)

Those of us who are living in central—north-central New Mexico and those of you from the other regions of New Mexico and other states have enjoyed "going up the Pecos" for many years. Whether you picnicked with family on holidays in the 50s, fly fished in the Pecos all years, or hiked in the Pecos Wilderness, we all have enjoyed "getting out" and seeing the colors in the canyons.

If you were interested in old mine dumps and pyrite cubes then you played on the dumps of **the** above mine, which was often called "Tererro mine." The mine was very clearly visible on the then dirt road leading to Cowles. **All** of this has changed and is still changing. The road is now paved, the canyons and meadows are filling with log homes, and the dumps of an old famous mine are coming down.

Location

The Hamilton mine (and other names) is located in the Willow Creek district, San Miguel County, northeast of Santa Fe some 17 mi via 1-25 taking the Glorieta—Pecos exit into the town of Pecos. At Pecos turn left 13 mi past the Benedictine Monastery, Monastery Lake, and the New Mexico Department of Game and Fish hatchery to eventually start the hill climb at the Tererro general store and post office (second one, original was at the mining camp), and then after an additional 1.6 mi farther you start seeing the old mining dumps. At an elevation of 8,000 ft and sandwiched between towering cliffs of pink and brown granite, one truly enjoys "getting out."

History

The "Tererro mine," as it is sometimes known ("Tererro" is a corruption or misspelling of the Spanish word "terrero" meaning mound, dump, place for mine waste), had other names in its short history. Several sources report knowledge of the zinc-lead-copper deposits being worked in the 1880s. In 1881 the Pecos ore body was discovered by a prospector named Case. He apparently sold out, as at that time the deposits were referred to as "Hamilton" or "Cowles" mine of the Pecos Copper Company, A.H. Cowles being the name of the principal owner of the company. Small amounts of copper ore were mined and hauled by wagon to Glorieta where it was shipped by rail to El Paso for smelting. Goodrich—Lockhart Company acquired the mine in 1916. Large-scale mining did not start until 1925 when the American Metal Company (American Metal Climax, now Cyprus—Amax) took over. A 600-ton flotation mill, "El Molino," was built 12 mi to the southwest in Los Alamitos Canyon. Ore was transported via aerial tramway some 1,000 ft above the valley floor. The tram was reported to be the longest aerial tram in North America. For shipping of the concentrate, the railroad built a spur from the mainline into the mill. It was later reported that when the reclamation of the mill site was done there was no trace of the railroad spur (E. Duran, pers. comm. 1999). Lead, zinc, copper, gold, and silver ore production amounted to 700 tons a day valued at 40 million dollars. Rich ore contained 16% zinc, 4% lead, 1% copper, 3 oz of silver/ton, and 0.1 g of gold/ton. Total ore mined and milled for the entire period of operation exceeded 1.5 million tons. The mine operated successfully from 1929 to 1939 with occasional disruptions of water in tunnels and labor dissatisfaction. The mine had an ongoing employment of over 700 men and was considered the largest mine in terms of payroll in New Mexico. Work was in progress 7 days a week, 16 hrs a day with shift alternation. It supported a bustling camp of over 3,000 people, 200 homes, mine buildings, two stores, first post office, hospital, boarding house, school, teacher's apartments, a bunkhouse, a nine-hole golf course, and a professional baseball team.

Geology

A strange arrangement (my term) of sediment from ancient seas compacted to form shales and siltstone and mixed at the surface with volcanic flows and intrusive igneous rocks. Rock formation is dated at Precambrian. The rocks later underwent compressive movement crumpling the rocks into tightly compressed folds during mountain building. Extreme heat and pressure recrystallized the sedimentary and igneous rocks into metamorphic equivalents such as quartzite, mica, schist, and phyllites. At the Pecos mine site the prevailing rock is an amphibolite with biotite-hornblende, along with feldspar and pyrite present in granular form. The ore deposits formed a zone 60 ft wide in this amphibolite changing it to a chloritic schist containing biotite and tourmaline along with pyrite, chalcopyrite, and sphalerite.

The first tunnel was cut at the level of Willow Creek, and an 1,800-ft shaft put in later extended to 400 ft. Copper ore grading 17% was mined from this shaft. In 1925 when American Metal Company took over, two additional shafts, the Katydid and the Evangeline, were put down at two separate ore zones, one more than 1,000 ft.

Mineralogy

According to Northrop's *Minerals of New Mexico,* 1944 and 1959 revised editions and the 1996 edition revised by Florence LaBruzza, some 41 minerals could be found in the Willow Creek district.

They include:

Actinolite (good crystals several inches in length)	Magnetite (micro)
Albite	Malachite
Anglesite	Microcline
Apatite	Monazite
Argentite (rare)	Muscovite
Biotite	Orthoclase
Bornite (rare)	Perthite
Cerussite	Proustite (micro, 1931)
Chalcanthite	Pyrite (1/2 inch cubes)
Chalcopyrite	Pyroxene group
Chrysocolla	Pyrrhotite
Copper (float, rare)	Quartz
Epidote (micro)	Roscoelite
Fluorite (pegmatite)	Rutile
Galena	Smithsonite
Garnet (Pyrope, Spessartite)	Sphalerite-Mannatite
Gold (lode & placer)	Sphene
Hornblende	Titanite
Kaolinite	

Mining

No further mining of the ore bodies has taken place since 1939. Lease rights exist with Cyprus—Amax Minerals of Englewood, Colorado. They are administered by and access is controlled by both the mining company and the New Mexico Department of Game and Fish (J.W. Greene, Cyprus—Amax, and J. Pederson, NM Dept. Game and Fish, pers. comm. 1999). The mine site in fenced and posted against "trespassing, safety hazards, open mine shafts, unstable material, hazardous substances, and unsafe drinking water." In 1998, Duran Sand and Gravel of Pecos was awarded a contract (1999-2000) by Cyprus—Amax under authority of NMDG&F (Abandoned Mines Act) to "reclaim and restore to near natural state as possible" the El Molino mill in Los Alamitos Canyon. The mill buildings, tram, and buildings at the mine were razed according to lease in 1939. In 1999 the reclamation is complete for the mill site with burying of waste some 60 ft, leveling of hill where mill building sloped, total reseeding with native grasses and flowers, and creation of wet lands. The 1998 Reclamation Award was given to Cyprus—Amax for this project, and, as of this symposium, reclamation of large magnitude is underway on the old mine site.

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A geological traverse of the Baja Peninsula, Mexico

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(Location 8 on index map)

Geologically, the Baja Peninsula is a complex mix of the three basic rock types that span the geological time scale from Precambrian metamorphic rocks to Holocene marine gravels and terrestrially derived alluvium. Stretching from Tijuana in the northwest to Calmalli several kilometers north of the boundary between Baja Norte and Baja Sur is a series of Late Jurassic–Early Cretaceous intrusions predominantly granite pegmatites and batholiths. Early to middle Cretaceous sedimentary rocks of marine and continental origin are intermittently exposed
with the intrusive rocks.

A major part of Baja Sur is Miocene to Holocene continental volcanic rocks. The tip of the peninsula is, once again, intrusive granite pegmatites and batholiths of middle Mesozoic age, the same type as the exposures in Baja Norte. Pliocene to Pleistocene fossils are readily exposed in the roadcuts along Mexico Highway 1. These are mainly marine gastropods, pelecypods, and ostracods. Sharks' teeth have also been noted from roadcuts between Ciudad Constitucion and La Paz.

At the northern extreme of the metamorphic and igneous intrusive rocks in Baja Norte, one finds extensive pegmatite deposits, a continuation of the same pegmatites of southern California. These rocks also host gold mineralization. But, the more spectacular gold specimens from Baja have come from the south-central part of Baja Norte, east of Guerrero Negro at Calmalli and El Arco. El Arco is the site of a more recent major copper deposit in the central peninsula. San Felipe is another notable mineral locality in Baja Norte known for its sulfur deposits.

In Baja Sur, the rich copper deposits from the Boleo district of Santa Rosalia are the best known of any mineral occurrence. Rare copper and lead hydroxyl chlorides such as boleite, cumengite, and pseudoboleite claim the Boleo district for their type locality. Gypsum crystals up to a meter and more are reported from several washes north of Santa Rosalia, and just off the coast southeast of Santa Rosalia in the Sea of Cortez is Isla San Marcos, a well-known and still-operating gypsum mine. Sulfur is associated with the geothermal area on the flanks of the Tres Virgins. Other minerals noted from Baja Sur are boulangerite, black tourmaline, and sulfur from localities south of La Paz.

Table 1—Abbreviated list of minerals from the Boleo district

Anglesite	Chrysocolla	Malachite
Anhydrite	Copper	Paratacamite
Apatite	Covellite	Phosgenite
Aragonite	Cumengite	Pseudoboleite
Azurite	Cuprite	Pyrite
Barite	Dolomite	Pyrolusite
Boleite	Epidote	Pyromorphite
Bornite	Galena	Quartz
Calcite	Gypsum	Silver
Chalcocite	Hematite	Smithsonite
Chalcopyrite	Magnesite	Tenorite

Table 2—Abbreviated list of minerals from Baja California Norte

Albite	Covellite	Orthoclase
Analcime	Danburite	Prehnite
Andalusite	Diopside	Rutile
Andradite	Dioptase	Scheelite
Beryl	Dravite	Schorl
Biotite	Elbaite	Stilbite
Bornite	Ferro-axinite	Talc
Calcite	Fluorapatite	Topaz
Chalcanthite	Forsterite	Turquoise
Chalcocite	Grossular	Wavellite
Clinozoisite	Lepidolite	Wollastonite
Copper	Magnetite	Zoisite

Table 3—Abbreviated list of minerals from Baja California Sur outside of the Boleo district Allophane

	Cryptomelane	Pyrope
Arsenopyrite	Halotrichite	Silver
Boulangerite	Hematite	Smithsonite

Bournonite	Jamesonite	Spessartine
Bromargyrite	Marcasite	Stephanite
Cerussite	Minium	Stibnite
Chiorargyrite	Pyromorphite	Tetrahedrite

Table 4—Abbreviated list of other minerals from the Baja Peninsula

Acanthite	Cuprite	Halite
Actinolite	Epidote	Pyrite
AImandine	Galena	Ramsdellite
Azurite	Goethite	Sphalerite
Chalcopyrite	Gold	Sulfur
Chrysocolla	Gypsum	

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The ugly ores of silver—part II, a photo gallery

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At the New Mexico Mineral Symposium in 1996, I presented a paper by the same title, Part I, where I described the more famous occurrences of the various silver minerals, including their mining history.

Part II of the "Ugly ores of silver" includes a photo presentation of some of the more common silver minerals, from both classic localities and some not so well known. Most are from some of the classic western United States localities.

The minerals featured in this presentation include the following:

Mineral	Formula	Association	Mine	District	County/ Province	State/ Country
Native Silver			Constancia		Charnacillo	Chile
Native Silver				Seven Troughs	Pershing	NV
Native Silver			Pansey Lee	Ten Mile	Humboldt	NV
Acanthite	Ag_2S		Cortland	Goldbrick	Gunnison	CO
Acanthite	Ag_2S		Ingleterra	Santa Eulalia	Chihuahua	MEX
Acanthite	Ag_2S	Matildite $AgBiS_2$	DeLamar	Silver City	Owyhee	ID
Acanthite	Ag_2S	Polybasite, Matildite, Azurite	Mollie Gibson	Aspen	Pitkin	CO
Acanthite	Ag_2S	Chlorargyrite, AgCl	Centennial–Eureka	Tintic	Juab	UT
Acanthite	Ag_2S		Blaine	Silver City	Owyhee	ID
Acanthite	Ag_2S	Chlorargyrite	Princess of India	Idaho Springs	Clear Creek	CO
Dyscrasite	Ag_3Sb		Constancia		Charnacillo	Chile
Stromeyerite	$AgCuS$		Magma	Superior	Pinal	AZ
Stromeyerite	$AgCuS$		Little Giant	Red Elephant Mtn.	Clear Creek	CO
Stephanite	Ag_5SbS_4	Sternbergite, $AgFe_2S_3$	Highland Bell		Beaverdell, British Columbia	CAN
Stephanite	Ag_5SbS_4	Acanthite Polybasite Chalcopyrite	C & C	Comstock lode, Virginia City	Washoe	NV
Stephanite	Ag_5SbS_4		Cortland	Goldbrick	Gunnison	CO
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$		American Sisters	Georgetown	Clear Creek	CO
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$	Acanthite	American Nettie	Red Mountain	Ouray	CO
Miargyrite	$AgSbS_2$		Kelly	Red Mountain	San Bernardino	CA
Miargyrite	$AgSbS_2$		Santa Fe	Red Mountain	San Bernardino	CA
Matildite	$AgBiS_2$		Grand Trunk	Montezuma	Summit	CO
Matildite	$AgBiS_2$	Aikinite, $PbCuBiS_3$	Alaska	Poughkeepsie Gulch	San Juan	CO
Pyrargyrite	Ag_3SbS_3		Yankee Boy	Red Mountain	Ouray	CO
Pyrargyrite	Ag_3SbS_3	Acanthite	Fraction	Tonapah	Nye	NV
Pyrargyrite	Ag_3SbS_3		Pelican	Hermosa	Sierra	NM
Pyrargyrite	Ag_3SbS_3	Polybasite Acanthite	Fraction vein, Jim Butler	Tonapah	Nye	NV
Pyrargyrite	Ag_3SbS_3	Acanthite Polybasite	Ilma	Lake City	Hinsdale	CO
Pyrargyrite	Ag_3SbS_3	Acanthite Polybasite	Emma	Dunton	Dolores	CO
Pyrargyrite	Ag_3SbS_3		Cortland	Gold Brick	Gunnison	CO
Chlorargyrite	$AgCl$		Bridal Chamber	Lake Valley	Sierra	NM
Chlorargyrite	$AgCl$		Calico	Calico	San Bernardino	CA
Chlorargyrite	$AgCl$	Galena	Lincoln	Georgetown	Clear Creek	CO
Bromargyrite	$AgBr$		Black Prince		Granite	MT
Bromargyrite	$AgBr$	Cerussite		Calico	San Bernardino	CA
Bromargyrite	$AgBr$	Galena	Utah–Eureka	Tintic	Juab	UT
Bromargyrite	$AgBr$		Santa Ana	Tombstone	Cochise	AZ
Bromargyrite	$AgBr$			Chloride Flat, Silver City	Grant	NM

Mineral	Formula	Association	Mine	District	County/ Province	State/ Country
Iodargyrite	AgI		Commonwealth	Pearce	Cochise	AZ
Tetrahedrite var Freibergite	$(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$		Highland Park	Bingham Canyon	Tooele	UT
Tetrahedrite var Freibergite	$(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$	Acanthite	Silver King Coalition	Park City	Summit	UT
Argentiferous Galena			Aspen	Silverton	San Juan	CO
Argentiferous "Steel" Galena			Bob Tail	Blackhawk	Gilpin	CO
Argentiferous "Steel" Galena			Red Elephant	Wood River	Hailey	ID

All of the above specimens were collected over a period of 40 yrs and were obtained primarily through the purchase of collections or museum trades. They were selected either for their crystallinity or their unique or rare locality. Identification of the silver minerals was confirmed by optical and x-ray diffraction analyses. The above silver minerals represent approximately 20% of my total collection of the "Ugly ores of silver."

Causes of color in minerals and gemstones—part 2

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The colors that one sees when looking at a mineral or gemstone are due to the response of that person's eye to the energies of the light, the emission spectrum of the illumination, and, most importantly, physical phenomena in the material that cause some colors to be absorbed while others are undisturbed or enhanced. It is beyond the scope of this talk to do more than touch on the physiology of the eye that allows us to see colors. Likewise, we will not dwell on the emission spectra of various light sources. Rather, we will concentrate on the various ways in which materials, especially minerals and their heights of perfection, gemstones, produce color from white light.

Light is a form of energy (electromagnetic energy), and white light is a mixture of all of the visible energies (or wavelengths). In order for a mineral to cause color from white light it has to somehow perturb the balance of the light energies. Kurt Nassau[23] has separated the causes of color into 15 mechanisms based on five physical groupings. Although there are some color mechanisms that depend on direct emission of certain colors, most of the mechanisms we are interested in depend on the ability of minerals to preferentially absorb certain energies of light. When these energies are removed from the white light the mineral is colored by the complementary color as demonstrated by the CIE* Chromaticity Diagram.

Last year's talk concentrated on the nature of light, a bit on the physiological aspects of color vision, a quick listing of the 15 mechanisms (according to Nassau), and discussions of two well-known coloring mechanisms— transition metal absorption and intervalence charge transfer. Transition metal absorption examples included ruby, emerald, and alexandrite. Intervalence charge transfer examples included sapphire, amazonite, and lapis lazuli.

This year's talk will briefly review some basic concepts of last year's talk and then go on to discuss two more absorption-type mechanisms—color centers (fluorite, smoky quartz, amethyst) and band-gap colors (yellow and blue diamonds, cuprite, cinnabar). Then it will describe how colors are caused by physical phenomena such as scattering (cat's eyes, stars, opalescence), dispersion (fire in diamonds), interference (labradorite), and diffraction (play of colors in opal).

Color centers (also known as F-centers or farbe {German for color) centers) are created when atoms are oxidized or removed. This is usually done by radiation. In most cases the hole left behind is occupied by an electron trying to proxy for the missing atom. This electron comes from a neighboring atom, and the unpaired electron left behind is prone to absorb light energy and thereby create colors. The most familiar examples of minerals colored by color centers are amethyst and smoky quartz, but fluorite, green diamonds, and brown topaz are also good examples. Color centers are one of the few coloring mechanisms that can be removed by heating or exposing the mineral to strong light.

Band-gap colors are produced in insulating and semiconducting materials. They require an energy gap between the valence and conduction energy in the electronic structure of an atom. If the energy band includes all wavelengths of light the material is white or clear and an insulator. If the band includes the energies of part of the visible spectrum the material is a semiconductor and colored. Some insulators can be band-gap colored by impurities. Examples of minerals colored by band-gap mechanisms are diamonds, cinnabar, and cuprite.

Scattering of light can cause colors to appear because blue light is more apt to be scattered than red. Scattering is caused by submicroscopic (the finer the better) grains of solid or liquid material. It can even be caused by random collisions of gas molecules in the atmosphere. Scattering is responsible for the blue of the sky, the white of clouds (and bull quartz), and the red color of sunsets. Minerals that display a special case of scattering are moonstones, cat's eye, and asterated (star) stones.

When white light enters a transparent medium of differing refractive index at an oblique angle, the light path is bent; it is refracted. Each of the colors is refracted to a slightly different angle; the colors are dispersed. If the light is allowed to exit the medium via a plane parallel to the entrance surface, the light will recombine to white. But if the entrance and exit planes are not parallel, the various colors will exit via different paths and produce little rainbows of color. Dispersion colors are the "fire" that we associate with faceted stones, especially diamonds.

Interference colors are caused when light travels obliquely through materials with thin layers of differing refractive index. The layers have to be about as thick as a wavelength of light. A coherent ray of light shining through the material is dispersed in the new medium. At each interface some of the light is reflected back up and some continues on down. If the layers are of such a thickness that a particular color is retarded by exactly one or a few integral wavelengths, the reflected ray of color and its refracted then reflected counterpart will constructively interfere with each other and that color will be bright. Those colors that are an integer and one half retarded will be destructively interfered and therefore cancelled out. Retardations between those extremes are muted. The effect is the schiller we associate with oil slicks, labradorite, cryptoperthite types moonstones, etc.

Diffraction can be considered a special case of interference caused, not by lamellae, but by layers of fine spheres. Each sphere scatters the light impinging on it in a radial fashion. As the layers are tilted, different wavelengths are constructively interfered with in different directions producing not one color but a play of colors. The spheres have to be perfectly round, of the same, exact size (about the size of light waves), and packed into i perfect order or the play of colors will be killed. The perfect example is precious opal. An imperfect example is the rainbow of colors one sees when viewing a bright source of light through a fine screen or the cloth of an umbrella.

*Commission Internationale de l'Eclairage

Acknowledgments, references, and suggested

reading

2. Nassau, K., 1983, The physics and chemistry of color—the fifteen causes of color: John Wiley & Sons, New York, 454 pp.

3. Nassau, K., 1980, The causes of color: Scientific American, v. 243, no. 4, pp. 124-154. (Provides an excellent summary of the subject.)

4. Nassau, K., 1981, Cubic zirconia—an update: Gems and Gemology, v. 17, no. 1, pp. 9-19.

5. Fritsch, E., and Rossman, G. R., 1987, An update on color in gems, part 1—introduction and colors caused by dispersed metal ions: Gems and Gemology, v. 23, no. 3, pp. 126-139.

6. Nassau, K., and Valente, G. K., 1987, The seven types of yellow sapphire and their stability to light: Gems and Gemology, v. 23, no. 4, pp. 222-231.

7. Fritsch, E., and Rossman, G. R., 1988, An update on color in gems, part 2—colors involving multiple atoms and color centers: Gems and Gemology, v. 24, no. 1, pp. 3-15.

8. Fritsch, E., and Rossman, G. R., 1988, An update on color in gems, part 3—colors caused by band gaps and physical phenomena: Gems and Gemology, v. 24, no. 2, pp. 81-102. (Contains a table describing the causes of color for most gemstones.)

9. Fritsch, E., et al., 1990, Gem-quality cuprian-elbaite tourmalines from Sdo Jose da Batalha, Paraiba, Brazil: Gems and Gemology, v. 26, no. 3, pp. 189-205.

"Gems and Gemology" contains numerous articles that include discussions of particular coloring mechanisms (such as ref. 9), too many to be enumerated here.